Water Sources "Powering" Southern California:

Imported Water, Recycled Water, Ground Water, and Desalinated Water

An Analysis of the Energy Intensity of Water Supplies
for the West Basin and Central Basin Municipal Water Districts

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Overview

Southern California relies on imported and local water supplies for both potable and non-potable uses. Imported water travels great distances through both the California and Colorado Aqueducts before arriving in southern California, consuming a large amount of energy in the process. Local sources of water often require less energy and provide a sustainable supply of water. Three water source alternatives which are found or produced locally and could reduce the amount of imported water are ocean water, groundwater, and recycled water.

Energy requirements vary considerably between these four water sources. All water sources require pumping, treatment, and distribution. Differences in energy requirements arise from the varying pumping, treating, and distribution processes needed to produce water to meet appropriate standards. This study examines the energy needed to complete each process. Analysis of the total energy required to acquire, treat, and distribute water provides insight into which technologies and policies warrant priority for efficiency improvements.

Specifics of energy consumption examined in this study for each water source are as follows:

- Energy required to **import water** includes three processes: pumping from the California and Colorado River Aqueducts to treatment plants; treating water; and distributing water from the treatment plant to customers.

- **Desalination of ocean water** includes four processes: pumping water from the ocean to the desalination plant; desalting and treating water within the plant to standards; discharge of concentrate back to the ocean; and distributing water from the desalination plant to customers.

- **Groundwater** usage requires energy for three processes: pumping groundwater from local aquifers to treatment facilities; treating water to water standards; and distributing water from the treatment plant to the customers. Additional injection energy is needed for groundwater replenishment with recycled water.

- Energy required to **recycle water** includes three processes: pumping water from secondary treatment plants to tertiary treatment plants; tertiary treatment of the water, and distributing water from the treatment plant to the customers.

The preliminary energy intensity results of this study are summarized in the table on the following page. They indicate that recycled water is among the least energy-intensive supply options available, followed by groundwater that is naturally recharged and recharged with recycled water. Imported water and desalinated supplies are the most energy intensive options. East Branch State Water Project water is close in energy intensity to desalination figures based on current technology.

(Note that the recycled water energy figure reflects only the *marginal* energy required to treat wastewater after it has already been processed to meet legal discharge requirements, along with the energy to convey it to users.)

Summary of the Energy Intensity Analysis

The following table identifies the energy inputs to each of the water supplies, including estimated energy requirements for desalination. Details describing the Central Basin and West Basin system operations are included in the water source sections.

Energy Intensity of Water Supplies for Central and West Basin Water Districts

	af/yr	Percentage of Total Source Type	kWh/af Conveyance Pumping	kWh/af MWD Treatment	kWh/af Recycled Treatment	kWh/af Groundwater Pumping	kWh/af Groundwater Treatment	kWh/af Desalination	kWh/af CBMWD Distribution	Total kWh/af	Total kWh/year
Central Basin MWD											
Imported Deliveries											
State Water Project (SWP) [1]	29,916	43%	3,000	44	NA	NA	NA	NA	0	3,044	91,064,304
Colorado River Aqueduct (CRA) [1] (other that replenishment water)	39,654	57%	2,000	44	NA	NA	NA	NA	0	2,044	81,052,776
Groundwater [2]											
natural recharge	101,793	55%	0	0	NA	350	0	NA	0	350	35,627,703
replenished with SWP water [1]	11,105	6%	3,000	44	NA	350	0	NA	0	3,394	37,690,370
replenished with CRA water [1]	12,956	7%	2,000	44	NA	350	0	NA	0	2,394	31,016,683
replenished with recycled water	59,255	32%	0	0	0	350	0	NA	0	350	20,739,339
Recycled Water											
Los Coyotes	375	10%	0	NA	0	NA	NA	NA	285	285	106,875
San Jose Creek	3,375	90%	0	NA	0	NA	NA	NA	380	380	1,282,500

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	af/yr	Percentage of Total Source Type	kWh/af Conveyance Pumping	kWh/af MWD Treatment	kWh/af Recycled Treatment	kWh/af Groundwater Pumping	kWh/af Groundwater Treatment	kWh/af Desalination	kWh/af WBMWD Distribution	Total kWh/af	Total kWh/year
West Basin MWD											
Imported Deliveries											
State Water Project (SWP) [1]	57,559	43%	3,000	44	NA	NA	NA	NA	0	3,044	175,209,596
Colorado River Aqueduct (CRA) [1] (other that replenishment water)	76,300	57%	2,000	44	0	0	0	0	0	2,044	155,957,200
Groundwater [3]											
natural recharge	19,720	40%	0	0	NA	350	0	NA	0	350	6,902,030
replenished with (injected) SWP water [1]	9,367	19%	3,000	44	NA	350	0	NA	0	3,394	31,791,598
replenished with (injected) CRA water [1]	11,831	24%	2,000	44	NA	350	0	NA	0	2,394	28,323,432
replenished with (injected) recycled water	8,381	17%	205	0	790	350	0	NA	220	1,565	13,116,278
Recycled Water											
West Basin Treatment, Title 22	21,506	60%	205	NA	0	NA	NA	NA	285	490	10,537,940
West Basin Treatment, single-pass RO	14,337	40%	205	NA	790	NA	NA	NA	285	1,280	18,351,360
Ocean Desalination	22,400	100%	278	NA	0	NA	NA	4,430	0	4,708	105,459,200

Notes:

NA Not applicable

1 Imported water based on percentage of CRA and SWP water MWD received, averaged over an 11-year period.

2 Groundwater values include entire basin, Central Basin service area covers approximately 80% of the basin. Groundwater values are specific to aquifer characteristics, including depth, within the basin.

3 Groundwater values include entire basin, West Basin service area covers approximately 86% of the basin. Groundwater values are specific to aquifer characteristics, including depth, within the basin.

Energy Intensity of Water

Water systems in California, including extraction of "raw water" supplies from natural sources, conveyance, treatment and distribution, end-use, and wastewater treatment, account for one of the largest energy uses in the state.[1] The total energy embodied in a unit of delivered water (that is, the amount of energy required to transport, treat, and process a given amount of water) varies with location, source, and use within the state. In most areas, the energy intensity will increase in the future due to limits on water resources and regulatory requirements for water quality and other factors.[2]

> ***Energy intensity*** is the total amount of energy, calculated on a whole-system basis, required for the use of a given amount of water in a specific location.

The Water-Energy Nexus

Water and energy systems are interconnected in several important ways in California. Water systems both provide energy – through hydropower – and they consume large amounts of energy, through pumping. Critical elements of California's water infrastructure are highly energy intensive. Moving large quantities of water long distances and over significant elevation gains in California, treating and distributing it within the state's communities and rural areas, using it for various purposes, and treating the resulting wastewater, accounts for one of the largest uses of electrical energy in the state.[3] Improving the efficiency with which water is used provides an important opportunity to increase related energy efficiency. ("*Efficiency*" as used here describes the useful work or service provided by a given amount of water.) Significant potential economic as well as environmental benefits can be cost-effectively achieved in the energy sector through efficiency improvements in the state's water systems and through shifting to less energy intensive local sources.

Overview of Energy Inputs to Water Systems

There are four principle energy elements in water systems:

1. primary water extraction and supply delivery (imported and local)
2. treatment and distribution within service areas
3. on-site water pumping, treatment, and thermal inputs (heating and cooling)
4. wastewater collection and treatment

Pumping water in each of these four stages is energy-intensive. Other important components of energy embodied in water use include groundwater pumping, treatment and pressurization of the water supply systems, treatment and thermal energy (heating and cooling) applications at the point of end-use, and wastewater pumping and treatment.

1. ***Primary water extraction and supply delivery***

   Moving water from near sea-level in the Sacramento-San Joaquin delta to the San Joaquin-Tulare Lake Basin, the Central Coast, and Southern California, and from the Colorado River to metropolitan Southern California, is highly energy intensive. As noted, approximately 3,000 kWh is necessary to pump one acre-foot (AF) of SWP water to southern California, and 2,000 kWh is required to pump one AF of water through the CRA to southern California.[4] Groundwater pumping also requires significant amounts of energy depending on the depth of the source. (Data on groundwater is incomplete and difficult to obtain because California does not manage groundwater resources, other than in adjudicated basins, and meters and data reporting are not required.)

2. ***Treatment and distribution within service areas***

   Within local service areas, water is treated, pumped, and pressurized for distribution. Local conditions and sources determine both the treatment requirements and the energy required for pumping and pressurization.

3. ***On-site water pumping, treatment, and thermal inputs***

   Individual water users use energy to further treat water supplies (e.g. softeners, filters, etc.), circulate and pressurize water supplies (e.g. building circulation pumps), and heat and cool water for various purposes.

4. ***Wastewater collection and treatment***

   Finally, wastewater is collected and treated by a wastewater authority (unless a septic system or other alternative is being used). Wastewater is sometimes pumped to treatment facilities where gravity flow is not possible, and the standard treatment processes require energy for pumping, aeration, and other processes. (In cases where water is reclaimed and re-used, the calculation of total energy intensity is adjusted to account for wastewater as a *source* of water supply. The energy intensity generally includes the additional energy for treatment processes beyond the level required for wastewater discharge, plus distribution.)

The present analysis is restricted to the first two elements.

Calculating Energy Intensity

Total energy intensity, or the amount of energy required to facilitate the use of a given amount of water in a specific location, may be calculated by accounting for the summing the energy requirements for the following factors:

- imported supplies
- local supplies
- regional distribution
- treatment
- local distribution
- on-site thermal (heating or cooling)
- on-site pumping
- wastewater collection
- wastewater treatment

Water pumping, and specifically the long-distance transport of water in conveyance systems, is a major element of California's total demand for electricity as noted above. Water use (based on embodied energy) is the second or third largest consumer of electricity in a typical Southern California home after refrigerators and air conditioners. Electricity required to support water service in the typical home in Southern California is estimated at between 14% to 19% of total residential energy demand.[5] (If air conditioning is not a factor the figure is even higher.) Nearly three quarters of this energy demand is for pumping imported water.

Interbasin Transfers

California's water systems are uniquely energy-intensive, relative to national averages, due to the pumping requirements of major conveyance systems which move large volumes of water long distances and over thousands of feet in elevation lift. Some of the interbasin transfer systems (systems that move water from one watershed to another) are net energy producers, such as the San Francisco and Los Angeles aqueducts. Others, such as the State Water Project (SWP) and the Colorado River Aqueduct (CRA) require large amounts of electrical energy to convey water. On *average*, approximately 3,000 kWh is necessary to pump one AF of SWP water to southern California,[6] and 2,000 kWh is required to pump one AF of water through the CRA to southern California.[7]

Total energy savings for reducing *marginal* (e.g. imported) supplies of water in Southern California are estimated at about 3,500 kWh/af.[8] Conveyance over long distances and over mountain ranges accounts for this high energy intensity. In addition to avoiding the energy and other costs of pumping additional water supplies, there are environmental benefits through reduced extractions from stressed ecosystems such as the delta.

Imported Water:
The State Water Project and the Colorado River Aqueduct

The water diversion, conveyance, and storage systems developed in California in the 20th century are remarkable engineering accomplishments. These water works move millions of AF of water around the state annually. The state's 1,200-plus reservoirs have a total storage capacity of more than 42.7 million acre feet (maf).[9] The Central and West Basin Municipal Water Districts (MWDs) receive imported water from Northern California through the State Water Project and Colorado River water via the Colorado River Aqueduct. Metropolitan Water District of Southern California delivers both of these imported water supplies to the Central and West Basin Districts.

California's Major Interbasin Water Projects

The State Water Project

The State Water Project (SWP) is a state-owned system. It was built and is managed by the California Department of Water Resources (DWR). The SWP provides supplemental water for agricultural and urban uses.[10] SWP facilities include 28 dams and reservoirs, 22 pumping and generating plants, and nearly 660 miles of aqueducts.[11] (See map below.) Lake Oroville on the Feather River, the project's largest storage facility, has a total capacity of about 3.5 maf.[12] Oroville Dam is the tallest and one of the largest earth-fill dams in the United States.[13] The state has water rights on the Feather River in Northern California, which provides about 25% of the water the state project extracts from the delta. The other 75% is "surplus" water.

Water is pumped out of the delta for the SWP at two locations. In the northern Delta, Barker Slough Pumping Plant diverts water for delivery to Napa and Solano counties through the North Bay Aqueduct.[14] Further south at the Clifton Court Forebay, water is pumped into Bethany Reservoir by the Banks Pumping Plant. From Bethany Reservoir, the majority of the water is conveyed south in the 444-mile-long Governor Edmund G. Brown California Aqueduct to agricultural users in the San Joaquin Valley and to urban users in Southern California. The South Bay Pumping Plant also lifts water from the Bethany Reservoir into the South Bay Aqueduct.[15]

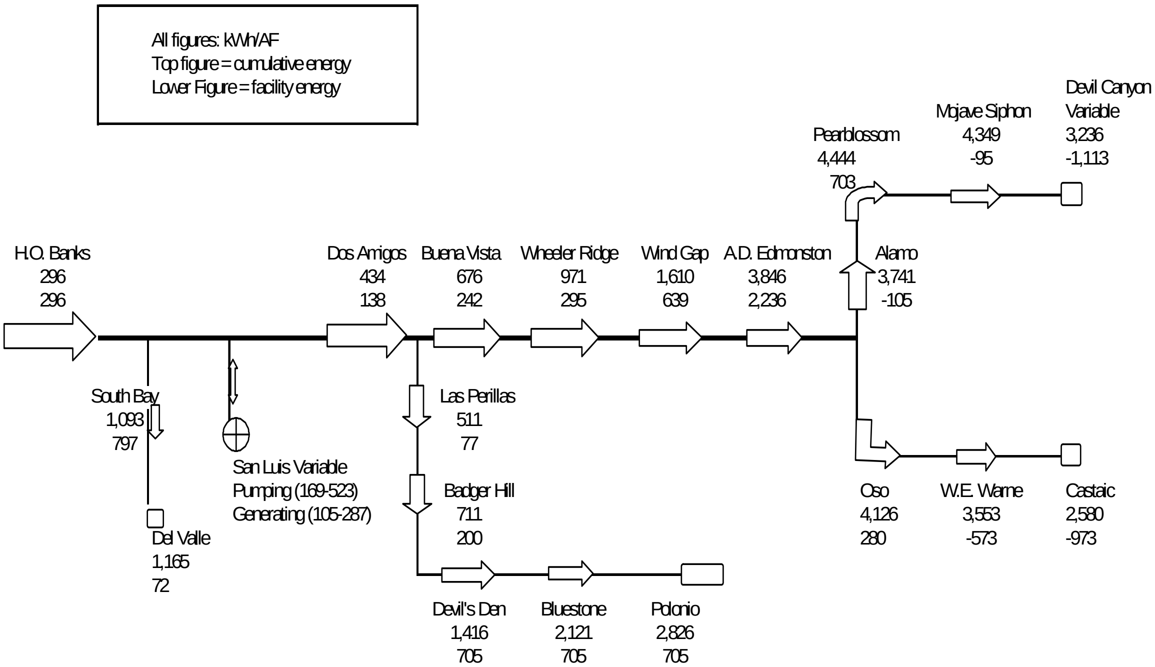
The State Water Project is the largest consumer of electrical energy in the state, requiring an average of 5,000 GWh per year.[16] The energy required to operate the SWP is provided by a combination of DWR's own hydroelectric and other generation plants and power purchased from other utilities. The project's eight hydroelectric power plants, including three pumping-generating plants, and a coal-fired plant produce enough electricity in a normal year to supply about two-thirds of the project's necessary power.

Energy requirements would be considerably higher if the SWP was delivering full entitlement volumes of water. The project has in fact been delivering an average of approximately 2.0 mafy, or half its contracted volumes, throughout the 1980s and 1990s.[17]

The following schematic shows each individual pumping unit on the State Water Project, along with data for both the individual and cumulative energy required to deliver an AF of water to that point in the system.

State Water Project
Kilowatt-Hours per Acre Foot Pumped

(Includes Transmission Losses)



Source: Based on data from: California Department of Water Resources, State Water Project Analysis Office, Division of Operations and Maintenance, *Bulletin 132-97*, 4/25/97.

Names and Locations of Primary State Water Delivery Facilities

The Colorado River Aqueduct

Significant volumes of water are imported to the Los Angeles Basin and San Diego in Southern California from the Colorado River via the Colorado River Aqueduct (CRA). The aqueduct was built by the Metropolitan Water District of Southern California (MWD). Though MWD's allotment of the Colorado River water is 550,000 afy, it has historically extracted as much as 1.3 mafy through a combination of waste reduction arrangements with IID (adding about 106,000 afy) and by using "surplus" water.[18] The Colorado River water supplies require about 2,000 kWh/af for conveyance to the Los Angeles basin.

The Colorado River Aqueduct extends 242 miles from Lake Havasu on the Colorado River to its terminal reservoir, Lake Mathews, near Riverside. The Colorado River aqueduct was completed in 1941 and expanded in 1961 to a capacity of more than 1 MAF per year. Five pumping plants lift the water 1,616 feet, over several mountain ranges, to southern California. To pump an average of 1.2 maf of water per year into the Los Angeles basin requires approximately 2,400 GWh of energy for the CRA's five pumping plants.[19] On average, the energy required to import Colorado River water is about 2,000 kWh/AF. The aqueduct was designed to carry a flow of 1,605 cfs (with the capacity for an additional 15%).

The sequence for pumping the water supplies is as follows: The Whitsett Pumping Plant elevates water from Lake Havasu 291 feet out of the Colorado River basin. At "mile 2," Gene pumping plant elevates water 303 feet to Iron Mountain pumping plant at mile 69, which then boosts the water another 144 feet. The last two pumping plants provide the highest lifts - Eagle Mountain, at mile 110, lifts the water 438 feet, and Hinds Pumping Plant, located at mile 126, lifts the water 441 feet.[20]

MWD has recently improved the system's energy efficiency. The average energy requirement for the CRA was reduced from approximately 2,100 kWh /af to about 2,000 kWh /af "through the increase in unit efficiencies provided through an energy efficiency program." The energy required to pump each af of water through the CRA is essentially constant, regardless of the total annual volume of water pumped. This is due to the 8-pump design at each pumping plant. The average pumping energy efficiency does not vary with the number of pumps operated, and the same 2,000 kWh /af estimate is appropriate for both the "Maximum Delivery Case" and the "Minimum Delivery Case."[21]

Based on the relatively steep grade of the CRA, limited active water storage, and transit times between plants, the system does not generally lend itself to shifting pumping loads from on-peak to off-peak. Under the Minimum Delivery Case, the reduced annual water deliveries would not necessarily bring a reduction in annual peak load, since an 8-pump flow may still need to be maintained in certain months.

Electricity to run the CRA pumps is provided by power from hydroelectric projects on the Colorado River as well as off-peak power purchased from a number of utilities. The Metropolitan Water District has contractual hydroelectric rights on the Colorado River to "more than 20 percent of the firm energy and contingent capacity of the Hoover power plant and 50 percent of the energy and capacity of the Parker power plant."[22] Energy purchased from utilities makes up approximately 25 percent of the remaining energy needed to power the Colorado River Aqueduct.[23]

Minimizing the Need for Inter-Basin Transfers

For over 100 years, California has sought to transfer water from one watershed for use in another. The practice has caused a number of problems. As of 2001, California law requires that the state examine ways to "*minimize the need to import water from other hydrologic regions*" and report on these approaches in the official State Water Plan.[24] A new focus and priority has been placed on developing *local* water supply sources, including re-use. The law directs the Department of Water Resources as follows:[25]

> The department, as a part of the preparation of the department's Bulletin 160-03, shall include in the California Water Plan a report on the development of regional and local water projects within each hydrologic region of the state, as described in the department's Bulletin 160-98, to improve water supplies to meet municipal, agricultural, and environmental water needs and *minimize the need to import water from other hydrologic regions*.

The legislation sets forth the range of local supply options to be considered:

> The report shall include, but is not limited to, regional and local water projects that use technologies for desalting brackish groundwater and ocean water, reclaiming water for use within the community generating the water to be reclaimed, the construction of improved potable water treatment facilities so that water from sources determined to be unsuitable can be used, and the construction of dual water systems and brine lines, particularly in connection with new developments and when replacing water piping in developed or redeveloped areas.

In fact, this law simply calls for a more thorough consideration in the state's official water planning process of work that is already going on in various areas of the state. The significance of the legislation is that for the first time, local supply development is designated as a priority in order to minimize inter-basin transfers.

Energy Requirements for the State Water Project and the Colorado River Aqueduct

Imported water, via the State Water Project, takes a similar path for both Central Basin MWD and West Basin MWD. The water is brought to southern California as described in the above sections, with a total conveyance expenditure of 3,000 kWh/af. This water passes through the MWD's treatment facilities, requiring 44 kWh/af, before it enters the Central Basin or West Basin distribution systems. Water pressure is sufficient to move supplies through the Central Basin or West Basin distribution system, without requiring additional pressure, and to the individual purveyors. The total energy required for State Water Project imported water is 3,044 kWh/af.

Imported water, via the Colorado River Aqueduct, also takes a similar path for both Central Basin and West Basin. The energy required to convey water to southern California is 2,000 kWh/af. An additional 44 kWh/af is required for MWD water treatment. No additional pressure is needed to move water through the Central Basin or West Basin distribution lines to the purveyors. The total energy required for Colorado River Aqueduct imported water is 2,044 kWh/af.

Groundwater and Recycled Water at Central and West Basin MWDs

Nearly half (46%) of the water used in the service area of the Metropolitan Water District of Southern California (Ventura to Mexico) is in fact secured from *local* sources, and the percentage of total supplies provided by local sources is growing steadily.[26] This figure is up from approximately one-third of the supply provided by local resources in the mid-1990s.[27] Metropolitan has encouraged local supply development through support for recycling, groundwater recovery, conservation, groundwater storage, and most recently, ocean desalination.

Groundwater and recycled water are important and growing sources for Central and West Basin MWDs. Water flows through natural hydrologic cycles continuously. The water we use today has made the journey many times. In water recycling programs, water is treated and re-used for various purposes including recharging groundwater aquifers. The treatment processes essentially short-circuit the longer-term process of natural evaporation and precipitation. In cities around the world water is used and then returned to natural water systems where it flows along to more users down stream. It is often used again and again before it flows to the ocean or to a terminal salt sink.

Groundwater at Central Basin and West Basin MWDs

Groundwater in the Central and West Basins is replenished with four water sources; natural recharge, SWP supplies, CRA supplies, and recycled water supplies. The majority of groundwater supplies are derived from natural recharge, approximately 55% in Central Basin and 40% in West Basin. The energy associated with natural recharge is minimal, 350 kWh/af for groundwater pumping.

Imported water, from both the SWP and CRA, is applied to spreading grounds for percolation into the groundwater supply in Central Basin and injected into the groundwater supply in West Basin. The imported water remains at sufficient pressure for injection, no additional energy is required. The energy requirements for importing water are significant, primarily due to the energy associated with importing the water from northern California and the Colorado River. The imported water also passes through MWD's treatment plant, incurring additional energy requirements. The total energy intensity for Central Basin MWD's and West Basin MWD's imported water from the SWP is 3,394 kWh/af for each MWD and from the CRA is 2,394 kWh/af for each MWD.

The final water source for groundwater is recycled water. Central Basin MWD replenishes groundwater with recycled water treated from two County Sanitation Districts of Los Angeles County operated plants, Los Coyotes Water Reclamation Plant and San Jose Creek Water Reclamation Plant. These plants recycle the water for direct discharge so no additional treatment or energy is required. The total energy requirement for groundwater replenishment with recycled water in Central Basin MWD is 350 kWh/af, the energy to pump the groundwater.

West Basin MWD replenishes groundwater by injecting single-pass RO recycled water from the West Basin Water Recycling Plant (WBWRP). The total energy use is 1,565 kWh/af. Details for the recycled water energy are described in the next section.

Recycled Water at Central Basin and West Basin MWDs

Many cities in California are using advanced processes and filtering technology to treat wastewater so it can be re-used for irrigation and other purposes. In response to increasing demands for water, limitations on imported water supplies, and the threat of drought, Central Basin MWD and West Basin MWD have developed state-of-the-art regional water recycling programs. Water is increasingly being used more than once within systems at both the end-use level and at the municipal level. This is because scarce water resources (and wastewater discharges) are increasing in cost and because cost-effective technologies and techniques for re-using water have been developed that meet health and safety requirements. At the end-use, water is recycled within processes such as cooling towers and industrial processes prior to entering the wastewater system. Once-through systems are increasingly being replaced by re-use technologies. At the municipal level, water re-use has become a significant source of supplies for both landscape irrigation (e.g. for freeways and golf courses) and for commercial and industrial processes. MWD is supporting 33 recycling programs in which treated wastewater is used for non-potable purposes.[28]

Central Basin MWD's program is comprised of two distribution systems, the E. Thornton Ibbetson Century Recycled Water Project and the Esteban Torres Rio Hondo Recycled Water Project, as well as three pumping stations and a reservoir. The Ibbetson Project and Torres Project are interconnected by an intricate 50-mile distribution system and operate as one recycled water supply system with water obtained through the Sanitation Districts of Los Angeles County, Los Coyotes Water Reclamation Plant and San Jose Creek Water Reclamation Plant. The combined projects, referred to as the Central Basin Recycled Water Project, deliver approximately 4,000 AF of recycled water annually to more than 150 industrial, commercial, and landscape irrigation sites. Central Basin's use of recycled water augments the precious groundwater and imported water supplies of southeast Los Angeles County.

Energy requirements are limited for recycled water in Central Basin. Treatment energy is not considered due to the fact that all water must be treated, regardless of the end use, recycled water or discharging to surface waters. The energy required to distribute the water throughout the Central Basin system is 285 kWh/af from the Los Coyotes Plant and 380 kWh/af from the San Jose Creek Plant.

Central Basin markets recycled water as a diverse and flexible tool for business and municipal use. The target customer is expanding from traditional irrigation users such as golf courses and parks to unconventional commercial and industrial users. Through innovative marketing, recycled water is now being used within textiles, paper production, dye houses, co-generation plants, and printing. Metropolitan State Hospital in Norwalk and U.S. Gypsum's paper mill in South Gate are among Central Basin's largest recycled water customers.

West Basin MWD provides customers with recycled water that is used for municipal, commercial and industrial applications. Approximately 27,000 AF of recycled water is annually distributed to more than 150 sites in the South Bay. These sites use recycled water for a wide range of non-potable applications. Based in El Segundo, California, the state-of-the-art West Basin Water Recycling Plant (WBWRP) is among the largest projects of its kind in the nation, producing five qualities of recycled water with the ultimate capacity to recycle 100,000 AF per year of wastewater from the Los Angeles Hyperion Treatment Plant (Hyperion) in El Segundo.

In 1998, West Basin began to construct the nation's only regional high-purity water treatment facility, the Carson Regional Water Recycling Plant (CRWRP). A pipeline stretching through five South Bay communities connects the CRWRP to West Basin's El Segundo facility. At the CRWRP, West Basin ultra-purifies the recycled water it gets from the El Segundo facility. From the CRWRP, West Basin uses service lines to transport two types of purified water to the BP/ARCO Refinery in Carson. The West Basin expansion also includes a new disposal pipeline to carry brine reject water from the CRWRP to a Los Angeles County Sanitation Districts outfall.

In order to provide perspective on the energy requirements for the WBWRP, two water qualities and associated energies are presented. Title 22 water, produced by a gravity filter treatment, requires conveyance pumping energy from Hyperion to WBWRP, 205 kWh/af. The water flows through the filters via gravity, thus no additional energy is required for treatment. The final energy requirement is 285 kWh/af for distribution with a total energy requirement of 490 kWh/af. This is the lowest grade of recycled water that WBWRP produces. Contrasting the Title 22 water, WBWRP produces single-pass RO water with a total energy requirement of 1,280 kWh/af. This energy demand includes 205 kWh/af for conveyance from Hyperion, 790 kWh/af for treatment with RO, and 285 kWh/af for distribution.

More than 170 South Bay sites use 9 billion gallons of West Basin's recycled water for non-drinking applications including irrigation, industrial processes, and indirect potable uses, seawater barrier injection. West Basin has been successful in changing the perception of recycled water from merely a conservation tool with minimal applications to a cost-effective business tool that can reduce production costs, water filtration costs, and limit the need for expensive chemicals and dyes.

Local oil refineries are major customers for West Basin's recycled water. The Chevron Refinery in El Segundo and the BP/ARCO Refinery in Carson use recycled water for their cooling towers. The Mobil Torrance Refinery and the Chevron Refinery in El Segundo use the water not only in its cooling towers but also in their boiler feed systems.

Ocean Water Desalination Development

Desalination technologies are proven. A number of approaches work well and produce high quality water. Many workable and proven technology options are available which remove salt from water. As evidenced by the quote from Aristotle above, the practice of desalination is ancient. During World War Two, desalination technology was developed as a water source for military operations.[29] Grand plans for nuclear-driven desalination systems in California were drawn up after the war, but they were never implemented due to cost and feasibility problems.

Desalination techniques range from distillation to recently-developed "reverse osmosis" (RO) technologies. Current applications around the world are dominated by the "multistage flash distillation" (MSF) process (at about 44% of the world's applications), and RO, (at about 42%).[30] Other desalting technologies include electrodialysis (6%), vapor compression (4%), multi-effect distillation (4%), and membrane softening (2%) to remove salts.[31]

Reverse Osmosis Membranes

A recent inventory of desalination facilities world-wide indicated that as of the beginning of 1998, a total of 12,451 desalting units with a total capacity of 6.72 afy[32] had been installed or contracted worldwide.[33] (Note that *capacity* does not indicate actual operation.) Non-seawater desalination plants have a capacity 7,620 af/d[34], whereas the seawater desalination plant capacity reached 10,781af/d.[35]

Desalination systems are being used in over 100 countries, but 10 countries are responsible for 75 percent of the capacity.[36] Almost half of the desalting capacity is used to desalt seawater in the Middle East and North Africa. Saudi Arabia ranks first in total capacity (about 24 percent of the world's capacity) followed by the United Arab Emirates and Kuwait, with most of the capacity being made up of seawater desalting units that use the distillation process.[37]

The salinity of ocean water varies, with the average generally exceeding 30 grams per liter (g/l).[38] The Pacific Ocean is 34-38 g/l, the Atlantic Ocean averages about 35 g/l, and the Persian Gulf is 45 g/l. Brackish water drops to 0.5 to 3.0 g/l.[39] Potable water salt levels should be below 0.5 g/l.

Reducing salt levels from over 30 g/l to 0.5 g/l and lower (drinking water standards) using existing technologies requires considerable amounts of energy, either for thermal processes or for the pressure to drive water through extremely fine filters (RO), or for some combination of thermal and pressure processes. Recent improvements in energy efficiency have reduced the amount of thermal and pumping energy required for the various processes, but high energy intensity is still an issue. The energy required is in part a function of the degree of salinity and the temperature of the water.

West Basin MWD is in the process of developing plans to construct an ocean desalinating plant. Through the planning stages, estimated daily energy requirements have been calculated. The values presented in this report are derived from the plant estimates for energy requirements. Conveyance energy required is 278 kWh/af to move the water from the ocean to the desalination plant. The total energy required to desalinate the ocean water is 4,430 kWh/af, assuming an energy recovery device is in place downstream of RO and averages 31% recovery. Current plans include blending the desalinated water with imported water and be distributed at the imported water pressure, thus no additional energy is required to distribute the water. The total energy requirement for desalinating water is 4,708 kWh/af.

Summary

This study examined the energy intensity of imported and local water supplies (ocean water, groundwater, and recycled water) for both potable and non-potable uses for Central and West Basin MWDs. All water sources require pumping, treatment, and distribution. Differences in energy requirements arise from varying pumping, treatment, and distribution processes needed to produce water to meet appropriate standards.

The key findings of this study are: 1) the marginal, or additional, energy required to treat and deliver recycled water is among the *least* energy intensive supply options available, 2) groundwater is low in energy intensity, though replenishment water (especially imported) is not, and 3) current desalination technology is getting close to the level of energy intensity of some imported supplies.

Further refinement of the data in this study will provide a more accurate basis for decision-making. The information presented, however, provides a reasonable basis for water managers to explore energy (and cost) benefits of increased use of recycled water, and it indicates that desalination of ocean water is getting close to the energy intensity of existing supplies.

Sources

[1] Water systems account for roughly 7% of California's electricity use: See Wilkinson, Robert C., 2000. Methodology For Analysis of The Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures, Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency.

[2] Franklin Burton, in a recent study for the Electric Power Research Institute (EPRI), includes the following elements in water systems: "Water systems involve the transportation of water from its source(s) of treatment plants, storage facilities, and the customer. Currently, most of the electricity used is for pumping; comparatively little is used in treatment. For most surface sources, treatment is required consisting usually of chemical addition, coagulation and settling, followed by filtration and disinfection. In the case of groundwater (well) systems, the treatment may consist only of disinfection with chlorine. In the future, however, implementation of new drinking water regulations will increase the use of higher energy consuming processes, such as ozone and membrane filtration." Burton, Franklin L., 1996, *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*. (Burton Engineering) Los Altos, CA, Report CR-106941, Electric Power Research Institute Report, p.3-1.

[3] Wilkinson, Robert C., 2000. *Methodology For Analysis of The Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures*, Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency.

[4] Metropolitan Water District of Southern California, *Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Power Operations*, 1996, p.5.

[5]QEI, Inc., 1992, *Electricity Efficiency Through Water Efficiency*, Report for the Southern California Edison Company, p. 24.

[6] Figures cited are *net* energy requirements (gross energy for pumping minus energy recovered through generation). The SWP supplies average 2,956 kWh/af for delivery pumping alone. An AF of water is the volume of water that would cover one acre to a depth of one foot. An AF equals 325,851 gallons, or 43,560 cubic feet, or 1233.65 cubic meters.

[7] Metropolitan Water District of Southern California, *Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Power Operations*, 1996, p.5.

[8] Wilkinson, Robert C., 2000. *Methodology For Analysis of The Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures*, Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency.

[9] California Department of Finance. California Statistical Abstract. Tables G-2, "Gross Capacities of Reservoirs by Hydrographic Region," and G-3 "Major Dams and Reservoirs of California." January 2001. (http://www.dof.ca.gov/html/fs_data/stat-abs/toc.htm)

[10] "The SWP, managed by the Department of Water Resources, is the largest state-built, multi-purpose water project in the country. Approximately 19 million of California's 32 million residents receive at least part of their water from the SWP. SWP water irrigates approximately 600,000 acres of farmland. The SWP was designed and built to deliver water, control floods, generate power, provide recreational opportunities, and enhance habitats for fish and wildlife." California Department of Water Resources, *Management of the California State Water Project*. Bulletin 132-96. p.xix.

[11] California Department of Water Resources, 1996, *Management of the California State Water Project*. Bulletin 132-96.p.xix.

[12] Three small reservoirs upstream of Lake Oroville — Lake Davis, Frenchman Lake, and Antelope Lake — are also SWP facilities. California Department of Water Resources, 1996, *Management of the California State Water Project.* Bulletin 132-96.

[13] California Department of Water Resources, 1996, *Management of the California State Water Project*. Bulletin 132-96. Power is generated at the Oroville Dam as water is released down the Feather River, which flows into the Sacramento River, through the Sacramento-San Joaquin Delta, and to the ocean through the San Francisco Bay.

[14] The North Bay Aqueduct was completed in 1988. (California Department of Water Resources, 1996, *Management of the California State Water Project*. Bulletin 132-96.)

[15] The South Bay Aqueduct provided initial deliveries for Alameda and Santa Clara counties in 1962 and has been fully operational since 1965. (California Department of Water Resources, 1996, *Management of the California State Water Project*. Bulletin 132-96.)

[16] Carrie Anderson, 1999, "Energy Use in the Supply, Use and Disposal of Water in California", Process Energy Group, Energy Efficiency Division, California Energy Commission, p.1.

[17] Average deliveries for 1980-89 were just under 2.0 mafy, deliveries for 1990-99 were just over 2.0 mafy. There is disagreement regarding the ability of the SWP to deliver the roughly 4.2 mafy that has been contracted for.

[18] According to MWD, "Metropolitan's annual dependable supply from the Colorado River is approximately 656,000 AF -- about 550,000 AF of entitlement and at least 106,000 AF obtained through a conservation program Metropolitan funds in the Imperial Irrigation District in the southeast corner of the state. However, Metropolitan has been allowed to take up to 1.3 maf of river water a year by diverting either surplus water or the unused portions of other agencies' apportionments." Metropolitan Water District of Southern California, 1999, "Fact Sheet" at: http://www.mwd.dst.ca.us/docs/fctsheet.htm.

[19] Metropolitan Water District of Southern California, 1999, http://www.mwd.dst.ca.us/pr/powres/summ.htm.

[20] The five pumping plants each have nine pumps. The plants are designed for a maximum flow of 225 cubic feet per second (cfs). The CRA is designed to operate at full capacity with eight pumps in operation at each plant (1800 cfs). The ninth pump operates as a spare to facilitating maintenance, emergency operations, and repairs. Metropolitan Water District of Southern California, 1999, Colorado River Aqueduct: http://aqueduct.mwd.dst.ca.us/areas/desert.htm, 08/01/99.

[21] Metropolitan Water District of Southern California, 1996, "Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Power Operations", 1996, p.5.

[22] Metropolitan Water District of Southern California, 1999, "Summary of Metropolitan's Power Operation". February, 1999, p.1, http://aqueduct.mwd.dst.ca.us/areas/desert.htm.

[23] Metropolitan Water District of Southern California, 1999, http://www.mwd.dst.ca.us/pr/powres/summ.htm. MWD provides further important system information as follows: Metropolitan owns and operates 305 miles of 230 kV transmission lines from the Mead Substation in southern Nevada. The transmission system is used to deliver power from Hoover and Parker to the CRA pumps. Additionally, Mead is the primary interconnection point for Metropolitan's economy energy purchases. Metropolitan's transmission system is interconnected with several utilities at multiple interconnection points. Metropolitan's CRA lies within Edison's control area. Resources for the load are contractually integrated with Edison's system pursuant to a Service and Interchange Agreement (Agreement), which terminates in 2017. Hoover and Parker resources provide spinning reserves and ramping capability, as well as peaking capacity and energy to Edison, thereby displacing higher cost alternative resources. Edison, in turn, provides Metropolitan with exchange energy, replacement capacity, supplemental power, dynamic control and use of Edison's transmission system.

[24] SB 672, Machado, 2001. California Water Plan: Urban Water Management Plans. (The law amended Section 10620 of, and adds Section 10013 to, the Water Code) September 2001. The next State Wtare Plan will be Bulletin 160-03 to be completed in 2003.

[25] SEC. 2. Section 10013 to the Water Code, 10013. (a) SB 672, Machado. California Water Plan: Urban Water Management Plans. September 2001, (Emphasis added.)

[26] Metropolitan Water District of Southern California, 2000. *The Regional Urban Water Management Plan for the Metropolitan Water District of Southern California*, p.A.2-3.

[27] "About 1.36 maf per year (34 percent) of the region's average supply is developed locally using groundwater basins and surface reservoirs and diversions to capture natural runoff." Metropolitan Water District of Southern California, 1996, "Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Power Operations", 1996, Vol.1, p.1-2.

[28] MWD estimates that reclaimed water will ultimately produce 190,000 AF of water annually. Metropolitan Water District of Southern California, 1999, "Fact Sheet" at: http://www.mwd.dst.ca.us/docs/fctsheet.htm.

[29] Buros notes that "American government, through creation and funding of the Office of Saline Water (OSW) in the early 1960s and its successor organizations like the Office of Water Research and echnology (OWRT), made one of the most concentrated efforts to develop the desalting industry. The American government actively funded research and development for over 30 years, spending about $300 million in the process. This money helped to provide much of the basic investigation of the different technologies for desalting sea and brackish waters." Buros, O.K., 2000. *The ABCs of Desalting, International Desalination Association*, Topfield, Massachusetts, p.5. This very useful summary is available at http://www.ida.bm/PDFS/Publications/ABCs.pdf

[30] Buros, O.K., 2000. *The ABCs of Desalting, International Desalination Association*, Topfield, Massachusetts, p.5. This very useful summary is available at http://www.ida.bm/PDFS/Publications/ABCs.pdf See also; Buros et al.1980. *The USAID Desalination Manual.* Produced by CH2M HILL International for the U.S. Agency for International Development.

[31] Wangnick,Klaus.1998 *IDA Worldwide Desalting Plants Inventory Report No.15.*Produced by Wangnick Consulting for International Desalination Association; and Buros, O.K., 2000. *The ABCs of Desalting, International Desalination Association*, Topfield, Massachusetts, p.5.

[32] Desalination systems with a unit size of 100 m3/d or more. Figures in original cited as 6,000 mgd.

[33] Wangnick Consulting GMBH (http://www.wangnick.com) maintains a permanent desalting plants inventory and publishes the results biennially in co-operation with the International Desalination Association, as the IDA Worldwide Desalting Plants Inventory Report. Thus far, fifteen reports have been published, with the latest report having data through the end of 1997; and see Wangnick,Klaus.*1998 IDA Worldwide Desalting Plants Inventory Report No.15.*Produced by Wangnick Consulting for International Desalination Association. The data cited are as of December 31, 1997.

[34] Cited in original as 9,400,000 m3/d.

[35] Wangnick,Klaus.*1998 IDA Worldwide Desalting Plants Inventory Report No.15.*Produced by Wangnick Consulting for International Desalination Association. (Cited in original in m3d (13,300,000 m3/d).

[36] Wangnick,Klaus.1998 *IDA Worldwide Desalting Plants Inventory Report No.15.*Produced by Wangnick Consulting for International Desalination Association; and Buros, O.K., 2000. *The ABCs of Desalting, International Desalination Association*, Topfield, Massachusetts. The United States ranks second in over-all capacity (16 %) with most of the capacity in the RO process used to treat brackish water. The largest plant, at Yuma, Arizona, is not in use.

[37] Wangnick,Klaus.1998. *IDA Worldwide Desalting Plants Inventory Report No.15.* Produced by Wangnick Consulting for International Desalination Association; and Buros, O.K., 2000. *The ABCs of Desalting, International Desalination Association*, Topfield, Massachusetts.

[38] Salinity levels referenced in metric units.

[39] OTV. 1999. "Desalinating seawater." Memotechnique, Planete Technical Section, No. 31 (February), p.1; and Gleick, Peter H. 2000. *The World's Water: 2000-2001*, Island Press, Covelo, p.94.